Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 3 (2015) 5838 – 5844

Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Design of an innovative mattress to improve sleep thermal comfort based on sleep positions

Su-Huey Tan, Tsu-Yu Shen, Fong-Gong Wu*

Department of Industrial Design, National Cheng Kung University, 1, Ta-Hsueh Road, Tainan, Taiwan 70101, Taiwan

Abstract

Recently, mattresses are designed and divided horizontally into several zones according to the main body segments under the static condition. However, different body segments have different thermal characteristics and sleeping postures change unconsciously during the night. Thus, the movements of the extremities should be taken into consideration in a bedding system design. With this in mind, the purposes of this study are: (1) to observe the changes of sleeping posture; and, (2) to develop an innovative mattress design based on the distributions of the body positions. A purposive sample of ten healthy participants (five males and five females) were selected to conduct the sleep monitoring in order to observe the dynamic and continuous features of their all-night sleeping postures. The images captured were then overlaid in order to acquire the distributions of the body positions on a mattress. The outcomes of sleep posture characteristics were used to provide a reference to conduct the mattress design to satisfy the needs of different body segments. Morphological analysis was used to find out the most suitable attributes for a mattress design. Finally, an innovative mattress design has been developed in this study. The proposed mattress has a four-layer sandwiched structure. A pilot study was conducted to evaluate the effect of the mattress on thermal comfort with 10 participants and a questionnaire was used to evaluate their subjective feelings on thermal comfort.

Peer-review under responsibility of AHFE Conference

Keywords: Sleep position; Body movements; Mattress; Sleep thermal comfort

* Corresponding author. Tel.: +886-6-2757575 ext. 54333; fax: +886-6-2746-088.
E-mail address: fonggong@mail.ncku.edu.tw

Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.839

1. Introduction

One third of human lives are spent in sleep, it is very important for the human body to recover from both physical and physiological fatigue suffered throughout the day [1]. With human development and advances in science and technology, bedding systems have attracted considerable attention. A good bedding system is universally accepted as one that provides comfortable support to the subject. The physical variables associated with comfort could include spinal alignment [2], contact pressure or weight distribution, interface skin temperature, and vapor exchange between the subject and the bedding system. Now, most of the studies and bedding system designs are focused on the measurement of back pressure to improve sleep quality and presented mainly in the way of mattress firmness, but lack of exploring the relationship between the sleeping postures and mattress design. As mattress is the familiar one, to achieve the local need of body sites [3] and sleep thermal comfort is one of the critical factors that affects sleep quality; the design of a bedding system surface that contacts the human body provides direct impact on sleep comfort. Several studies have investigated the thermal sensation and comfort of local and whole body. The results showed that local cold discomfort of feet is considered as the major source of discomfort under cold conditions [4-6]. Hence, whole body thermal comfort can be influenced by the local thermal comfort.

Nowadays, modern designs integrate different sleeping surfaces into bedding systems. The purpose of the design is to apply different materials or different structure to the surface according to the needs of the body parts in supine position under the static condition [2, 7]. However, sleep postures are changing unconsciously during the night [8]. Thus, the positions of the body segments are different in both the horizontal and vertical sleeping surface thereby affecting the overall and local thermal comfort. In addition, both skin temperature and sensitivity to thermal stimulus differs from area to area on the body surface [9]. Therefore, the movements of the extremities should be taken into consideration to provide a more comfortable sleeping environment besides the horizontal designs of the bedding which just satisfy the demand of the torso. Thus, the relationship between the sleep positions and sleeping surface is a crucial design issue in order to take account of the demands of different body segments.

Sleep posture variations differ from individual to individual when they feel uncomfortable and try to reduce sleep discomfort by redistribute the interface pressures of the body [7]. Several major sleep postures are repeated for 20-40 times throughout the night and each posture lasted for an average of 15 min [10, 11]. Most of the studies related to the sleep posture are mainly focused on preventing pressure sores for sickbed patients, obstructive sleep apnea and body movements monitoring among the elders [12-14]. However, all of these studies focused on the other fields rather than the bedding design. On the other hand, several researches have investigated the influence of different sleep postures on sleep and showed that poor sleepers spent more time on the backs with their heads straight [10, 15]. These studies have divided the sleep postures into two main categories, folded and straight, according to the positions of each body segment.

Therefore, the purposes of this study are: (1) to observe the changes of sleeping posture; and, (2) to develop an innovative mattress design based on the distributions of the body positions for improvement in sleep thermal comfort.

2. Methods

The mattress design process is comprised of two parts: sleeping postures observation and development of the mattress design. The observation of sleeping posture was integrated into the following idea generation stage of the mattress.

2.1. Sleeping postures observation

2.1.1. Participants

Ten healthy students, five males and five females, ranging in age from 20 to 25 years old, without sleep disorders participated in the experiment to investigate their sleep positions. None of the each participants took medication, caffeine or alcohol during the experiment. All the participants were of standard body (18.5 <BMI <24), average height of male was 168.4cm, female 162.0cm.

2.1.2. Procedures

Video footage for sleep recording principally helped diagnose sleep problems by observing slight body movement and position shift. The aim of the experiment was to observe the dynamic and continuous features of all-night sleep positions. Before coming into the sleep laboratory, all participants were instructed to conduct one week of adaptation to adjust their sleep time for experiment needs. For one laboratory night, participants came to the laboratory two hours before their habitual bedtime and dressed their own short pajamas. External markers were stuck around the joints (elbows, wrists, knees, and ankles) but not directly on the joints to reduce bone-to-skin artifact. A standard single mattress was prepared for participants to sleep on. Digital Video was set up just above the mattress for all night sleep position recording. Thin blankets were used to allow the researchers to observe movements of the limbs. The sleep period was from 11:30 p.m. to 08:00 a.m.

2.1.3. Analysis

2.1.3.1. The changes of sleeping posture

The recorded sleeping postures were categorized visually by the authors. Sleeping posture, which was defined as the posture that was maintained more than one minute, was analyzed for the whole night [10]. Using the data from the sleep monitoring session, sleeping postures were divided into major movements and minor movements. Major movements, refer to the large movement of the trunk, head and pelvis, were defined according to the angle between the horizontal line of the mattress and the body plane and divided into three typical sleep postures: supine, lateral and semi-lateral. To categorize the three sleeping postures, a critical value of 45 degrees was used to distinguish them [16]. The changes of sleeping posture were analyzed within the individuals.

2.1.3.2. Sleep position distributions

Minor movements were defined as folding and unfolding of the limbs. The image captured was analyzed according to the body parts of the participants. The joints of the body segments (shoulder, elbow, wrist, fingers, knee, ankle, heel and toes) were illustrated as circle with different proportions and colors. The heights of the participants were adjusted to a standard scale before the images were overlaid. To acquire the distributions of the body positions on a sleeping surface, the images captured were then overlaid based on the marker that was drawn on the sleeping surface with 5*5 grid. Fig. 1.below illustrates the distributions of the body positions on a mattress in both supine and lateral positions.

Through the observation of sleeping posture, some characteristics of sleep positions were found and the distribution of the sleep positions was analyzed.

2.2. Development of mattress design

2.2.1. Design principles

According to the previous studies on the principle of bedding-related human factors, design principles were set up. As spinal alignment was the fundamental of bedding system design, it was unnecessary to be discussed in this study. Besides the principles of spinal alignment, there were three design principles that a mattress design should cover, that was

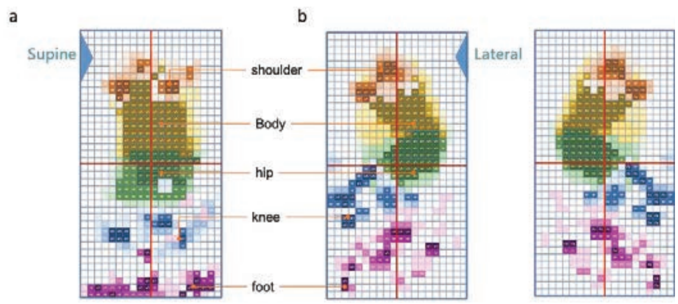

Fig. 1. (a) Distribution of supine positions; (b) Distribution of lateral positions.

- *Pressure redistribution*: A mattress design was required to conform to the body contours to avoid local point pressures on the human body tissue especially at the location of bony prominence.
- *Easy to change sleep position*: A mattress design should support human to change their sleep posture when they felt uncomfortable and tried to reduce sleep discomfort by redistributing the interface pressures of the body.
- *The physiological balance of microclimate*: With additional heat exchange between human body and the sleeping surface, the feeling of thermal comfort would be influenced directly.

With different sleeping positions, human body had different contact area with the sleeping surface. Therefore, design principles were applied to the major sleeping posture (supine and lateral) in order to meet the requirements of different body parts. The detailed information is presented in Table 1. Specific requirements of different body parts in supine and lateral positions were then developed based on the design criteria, as shown in Fig. 2.

Table 1. Design criteria for the supine and lateral positions.

Design principles	Design criteria	Sleep position	
		Supine	Lateral
Pressure redistribution	Avoid local point pressures especially at the location of bony prominence	Conform to the body contours	Increase contact area
Easy to change body position	Support the changes of sleeping posture	Provide local support (shoulder, thigh, heel)	
The physiological balance of microclimate	Avoid thermal discomfort caused by the skin temperature and skin wetness	Heat dissipation in proximal and warming in distal	Heat dissipation in proximal and keep warm in distal

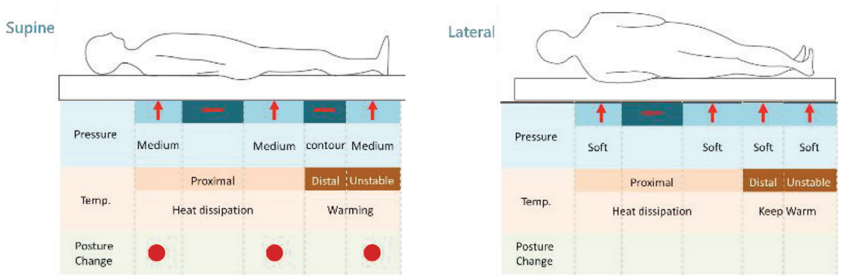

Fig. 2. Specific requirements of different body parts in supine and lateral positions.

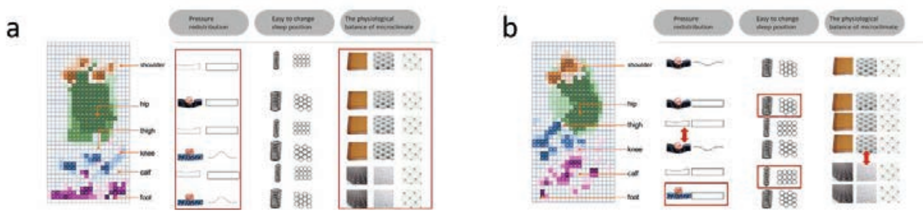

Fig. 3. Second stage of morphological analysis (a) Supine position ; (b) Lateral position.

2.2.2. Idea generation

Morphological analysis was adopted twice to generate different kinds of mattress matrices. In the first stage of morphological analysis, the possible designed area of a mattress (corners, borders, central and local) was aligned in the column and the principles was aligned in the row. Through brainstorming, the preliminary attributes of the mattress were generated.

In the second stage of morphological analysis, the three design principles were aligned in the column and the different parts of the human body were aligned in the row. Based on the design principles and the requirements of each body parts, the possible solutions for supine and lateral positions were found (Fig. 3). Next, the outcome of the first stage of morphological analysis was integrated with the second stage of morphological analysis. The sleep characteristics of the observation were adopted to provide a reference to conduct the mattress design to satisfy the needs of different body parts. Ranking the design principles according to their impact on human body, each idea was graded by their accumulate points. The most suitable combination would be chosen.

3. Result

An innovative mattress design has been developed in this study. The proposed mattress has a four-layer sandwiched structure, as shown in Fig. 4: the top layer has a V-shaped structure to increase the friction between the skin and the mattress; the second layer has a X-shaped structure where a different material has been used to increase the heat dissipation of the torso; the third layer is designed for ventilation and moisture transmission; and the bottom layer is designed for pressure redistribution. The first two layers are designed according to the changes of sleeping posture and their distribution on the sleeping surface, as shown in Fig. 5(a). Based on the design of the proposed mattress (mattress A), the second mattress (mattress B) has been developed. Mattress B has the similar structure with mattress A, a four-layer sandwiched structure, but different in the details of each layer. The first two layers of mattress B are presented in I-shaped, as shown in Fig. 5(b)

A pilot study was conducted to evaluate the effect of the mattresses on thermal comfort with 10 participants. The participants were instructed to sleep in the sleep laboratory for two consecutive nights. A 7-point scale of the subjective questionnaire was asked and recorded to evaluate their subjective feelings on thermal comfort before sleep and at the time of rising in the morning. The questionnaire consisting of local thermal comfort scale and whole thermal comfort and ranging from uncomfortable to comfortable in 7-point scale (-3 =very uncomfortable, -2 =uncomfortable, -1 = slightly uncomfortable, 0=neutral, 1=slightly comfortable, 2=comfortable, 3=very comfortable).

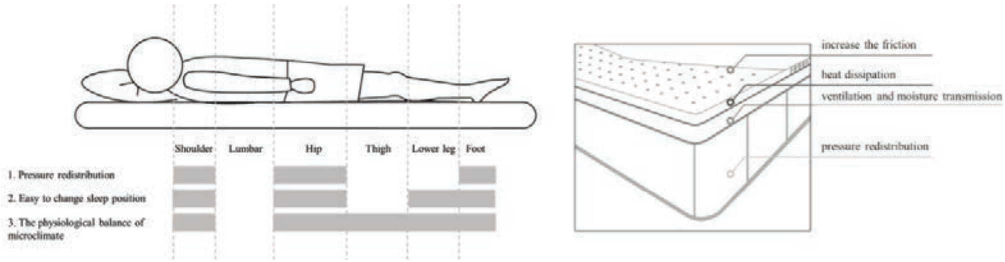

Fig. 4. A four-layer sandwiched structure of the proposed mattress.

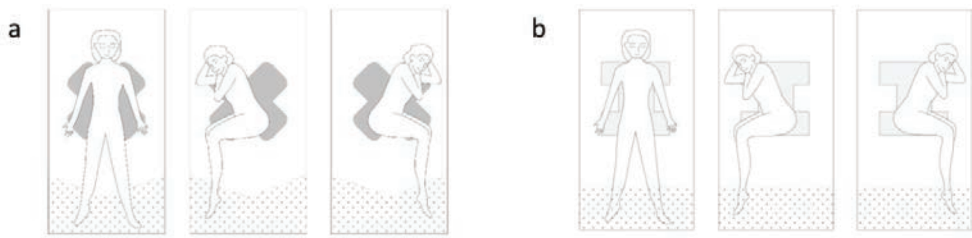

Fig. 5. (a) The X-shaped and V-shaped structure of mattress A. (b) The I-shaped structure of mattress B.

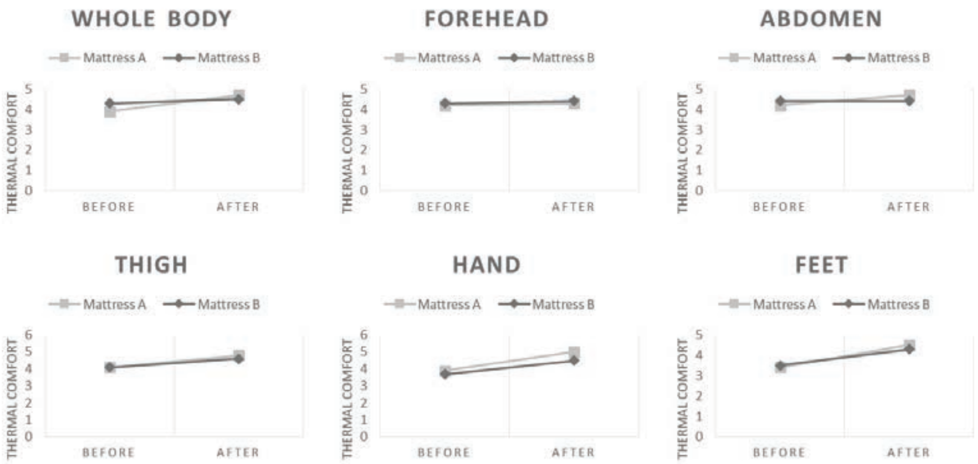

Fig. 6. Comparison of the mean of thermal comfort of different body parts between the two mattresses before and after sleep.

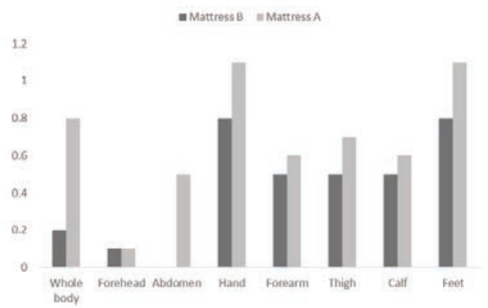

Fig. 7. Comparison of the mean difference of different body parts between the two mattresses.

The subjective perception of the participants regarding different mattresses on thermal comfort of different body parts are displayed in Fig. 6. It can be seen that all participants had a slightly higher comfortable sensation for mattress A at the time of rising in the morning. Although the perception of comfort of the abdomen for mattress A was lower before sleep, it was increased and surpassed abdominal comfort on mattress B at the time of rising in the morning. At the beginning of sleep, thermal comfort of the thighs and feet were almost the same between the two matresses, however, it can be seen that they had a higher grade in the Mattress A after sleep and the increment in feet thermal comfort was higher. Similar to the feet thermal comfort, participants had a higher perception of comfort of the hands in Mattress A after sleep. Althought participants had the same perception of comfort of forehead on both mattresses, the overall body thermal comfort was increased due to the increase of local thermal comfort. The mean difference of different body parts comparing the two mattresses is presented in Fig. 7. On the whole, all of the subjective perceptions of Mattress A was higher than that of the mattress B. A slight increase in the perception of local thermal comfort increased the perception of whole body thermal comfort.

4. Discussion and conclusion

An innovative mattress has been proposed in this study. According to the principle of bedding-related human factors, this study has developed a mattress design based on the combination of the distribution of sleep positions and the design principles. The four-layer sandwiched structure of the mattress A has their roles to play. First, the V-shaped structure at the top layer emphasize the warming of the lower extremities by increasing the friction between human skins and sleeping surface to improve sleep onset latency. Second, the X-shaped structure at the second layer emphasizes the dynamic changes of sleeping posture and improves heat dissipation. Third, ventilation and moisture transmission are improved by the alignment of holes with different diameters. Last, using different hardness of foam to achieve the pressure redistribution of human body. Following the design of the mattress A, mattress B has been developed based on the design structure of mattress A. Mattress B has the I-shaped structure on the top layer and second layer that are different from mattress A.

It is widely believed that the perception of thermal comfort was influenced directly by the design of the mattress. Thus, the upper layer where there was direct human body contact, thermal comfort could be increased by direct interaction between the human body and the sleeping surface. We speculated that thermal comfort of extremities had a slight increase and thus improved whole body thermal comfort probably because of the design on the first layer. As mentioned in the research of Li-Yen [3], whole body thermal comfort could be improved by the local thermal comfort, whereas this study also had the same result. Although the perceptions of thermal comfort of other body parts of mattress A increased, thermal comfort of the forehead remain similar to testing with the mattress B. One possible reason for the result may be the design of the second layer, which increased the heat dissipation of the torso. However, the perception of thermal comfort was quite subjective and might differ from individual to individual. Therefore, a further study is needed to be conducted to evaluate the proposed mattress more objectively. To sum up, the experimental result of the pilot study has shown that the proposed mattress A is capable of improving sleep thermal comfort than mattress B. A further experiment will be conducted in the future to modify the design of the mattress in order to improve thermal comfort during sleep.

Acknowledgements

The authors would like to thank the Ministry of Science and Technology in Republic of China for financially supporting this research under Contract no. MOST 103-2221-E-006 -197 -MY3.

References

[1] Opp, M.R., Sleeping to fuel the immune system: mammalian sleep and resistance to parasites. BMC evolutionary biology, 2009. **9**(1): p. 8.
[2] Lahm, R. and P.A. Iaizzo, Physiologic responses during rest on a sleep system at varied degrees of firmness in a normal population. Ergonomics, 2002. **45**(11): p. 798-815.
[3] Li-Yen, L., et al., A laboratory validation study of comfort and limit temperatures of four sleeping bags defined according to EN 13537 (2002). Applied Ergonomics, 2013. **44**(2): p. 321-6.
[4] Sakoi, T., et al., Thermal comfort, skin temperature distribution, and sensible heat loss distribution in the sitting posture in various asymmetric radiant fields. Building and Environment, 2007. **42**(12): p. 3984-3999.
[5] Arens, E., et al., Partial- and whole-body thermal sensation and comfort— Part I: Uniform environmental conditions. Journal of Thermal Biology, 2006. **31**(1–2): p. 53-59.
[6] Brooks, J. and K. Parsons, An ergonomics investigation into human thermal comfort using an automobile seat heated with encapsulated carbonized fabric (ECF). Ergonomics, 1999. **42**(5): p. 661-673.
[7] Park, S.J., et al., Comfort Evaluation and Bed Adjustment According to Sleeping Positions. Human Factors and Ergonomics in Manufacturing, 2009. **19**(2): p. 145-157.
[8] Aaronson, S.T., et al., Brain state and body position: a time-lapse video study of sleep. Archives of General Psychiatry, 1982. **39**(3): p. 330-335.
[9] Amrit, U.R., Bedding textiles and their influence on thermal comfort and sleep. AUTEX Research Journal, 2007. **8**(7).
[10] De Koninck, J., et al., Sleep positions in the young adult and their relationship with the subjective quality of sleep. Sleep, 1983. **6**(1): p. 52.
[11] Johnson, H., et al., In what positions do healthy people sleep? Journal of the American Medical Association, 1930. **94**(26): p. 2058-2062.
[12] Liu, J.J., et al. A dense pressure sensitive bedsheet design for unobtrusive sleep posture monitoring. in Pervasive Computing and Communications (PerCom), 2013 IEEE International Conference on. 2013. IEEE.
[13] Yousefi, R., et al. Bed posture classification for pressure ulcer prevention. in Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE. 2011. IEEE.
[14] Yu-ding, Z., et al., Body pressure distribution research and zone design of pocket spring mattresses. 2011 IEEE 18th International Conference on Industrial Engineering and Engineering Management (IE&EM 2011), 2011: p. 1656-1659.
[15] Agargun, M.Y., et al., Sleeping position, dream emotions, and subjective sleep quality. Sleep and Hypnosis, 2004. **6**: p. 8-13.
[16] Murayama, R., et al., The effects of instruction regarding sleep posture on the postural changes and sleep quality among middle-aged and elderly men: A preliminary study. Bioscience Trends, 2011. **5**(3): p. 111-119.